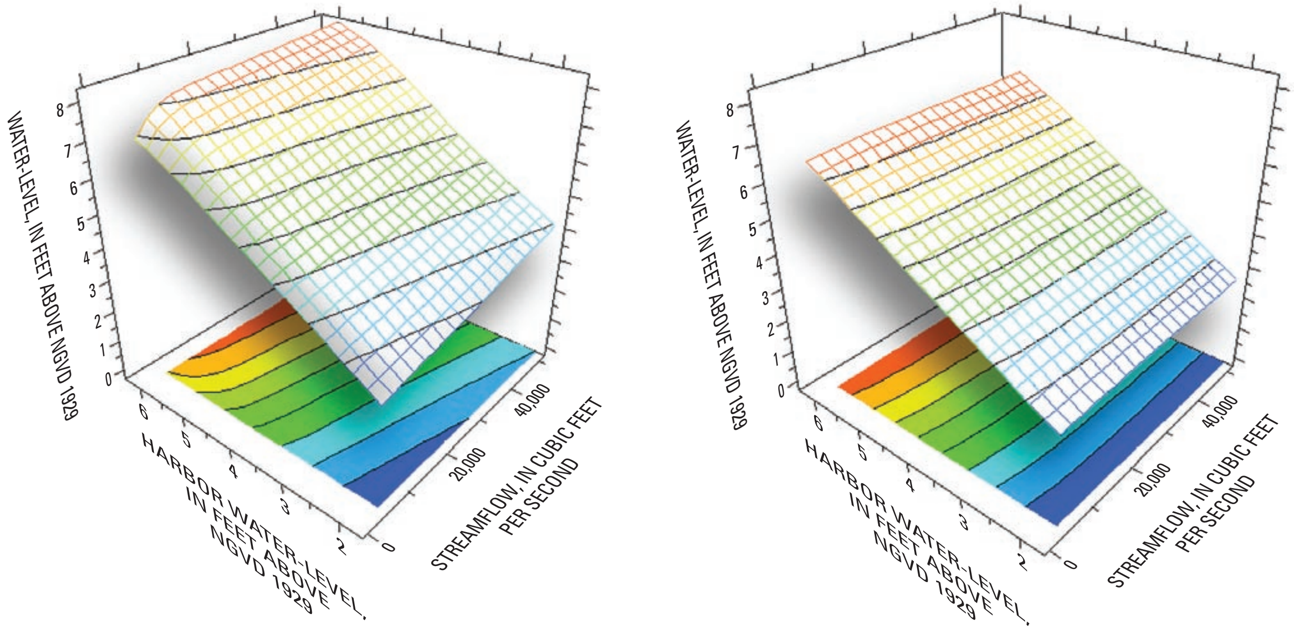


Little Black River at Limehouse (02198979)

Front River at Broad Street (02198977)

Figure 39. The interaction of harbor water level (FWL8980A) and streamflow (Q8500A) on local water levels at Little Back River at Limehouse (station 02198979, left response surface) and at Front River at Broad Street (station 02198977, right response surface). Both response surfaces show larger contributions of harbor water levels than streamflow on local water-level conditions. The response surface on the right shows negligible influence of streamflow on local water levels.

Development of a Model-to-Marsh Decision Support System

Dutta and others (1997) define DSSs as, "systems helping decision-makers to solve various semistructured and unstructured problems involving multiple attributes, objectives, and goals …. Historically, the majority of DSSs have been either computer implementations of mathematical models or extensions of database systems and traditional management information systems." Environmental resource managers commonly use complex mathematical (mechanistic) models based on first principles physical equations to evaluate options for using the resource without damage. While there appears to be no strict criteria that distinguish a DSS from other types of programs, Dutta and others (1997) suggest that artificial intelligence (AI) is a characteristic of more advanced DSSs, "With the help of AI techniques DSSs have incorporated the heuristic models of decision-makers and provided increasingly richer support for decision-making. AI systems have also benefited from DSS research as they have scaled down their goal from replacing to supporting decision makers."

The authors have previously developed a DSS to support the permitting of three water-reclamation facilities that discharge into South Carolina's Beaufort River estuary (Conrads and others, 2002b; Conrads and others, 2003; Conrads and Roehl, 2005). The Beaufort DSS incorporated a water-quality model comprising several dozen ANN "submodels" that simulated both point and nonpoint source effects on water quality throughout the system. ANN execution speeds were also found to be much faster than mechanistic models, greatly reducing the turn-around time for users performing waste load allocation scenarios. The Beaufort DSS was a spreadsheet application that connected the ANN super-model to a database storing time series of the area's rainfall and riverine water level, specific conductance, water temperature, and dissolved oxygen from seven different USGS gaging stations. The DSS could run 3-year simulations under different point and nonpoint loading scenarios while providing users with streaming tabular output and graphics to provide situational awareness. Its graphical user interface (GUI) requires no typing. These features make the DSS easily distributed and immediately usable by all stakeholders. The development, performance, and features of the Savannah DSS are described below.

The development of a DSS for the Savannah River Estuary and surrounding wetlands, called the Model-to-Marsh DSS (M2M), required a number of steps (described previously), including (1) merging all the data into a single comprehensive database, (2) developing water-level and salinity ANN submodels, and (3) developing of a spreadsheet application that integrates the new database, output from an existing 3D hydrodynamic model, and ANN submodels into a single package that is easy to use and readily disseminated.

Architecture

Figure 40 shows the basic architectural elements of the DSS. The DSS reads and writes files for the various run-time options that can be selected by the user through the system's GUI. A historical database contains 11 years of hydrodynamic data that are read into the simulator along with the ANN submodels at the start of a simulation. Using GUI controls, the user can evaluate alternative flow scenarios, or load specially formatted output files from the 3D hydrodynamic model that adjust historical riverine water level and specific conductance to evaluate alternative channel geometries and "replumbing" scenarios. The outputs generated by the simulator are written to files for post processing a spreadsheet application used by the DSS's "2D Color-Gradient Visualization Program". The DSS also provides streaming graphics during simulations, visually representing historical and simulated behaviors side-by-side. These features are described in more detail below.

Historical Database

The measured data required extensive clean up for a variety of problems, including erroneous and missing values and phase shifts. The locations of the gaging stations are shown in figures 1 and 5. The resulting database comprises 11 years of half-hourly data (≈160,000 time stamps) for 110 variables. A summary of the historical databases stored in the DSS is described below.

- Clyo streamflow (Q_{clyo}) and harbor water levels—11 years of half-hourly water-level measurements in Savannah Harbor at Fort Pulaski, Ga., and river flows measured inland at Clyo, Ga., by the USGS.
- USGS riverine water level and specific conductance—11 years of half-hourly measurements collected from four stations in the Savannah River Estuary by the USGS.
- GPA riverine water level and specific conductance—half-hourly measurements collected on behalf of the GPA from 14 stations over 3 months each in 1997 and 1999. Some stations recorded both surface and bottom specific-conductance measurements.
- USGS marsh water level and specific conductance—71 months (June 1999 to May 2005) of half-hourly measurements from seven stations.
- GPA marsh water level and specific conductance—40 months (June 1999 to October 2002) of half-hourly specific conductance and water-level measurements from 10 stations.

Linkage to the Three-Dimensional Hydrodynamic Model

The ANN super-model comprises 127 submodels that are configured as follows. Simulation models of water level and specific conductance at four USGS stations in the main channel of the river were developed using Savannah River streamflow data and Savannah Harbor water-level data for inputs, incorporating multiple time delays, moving window averages, and time derivatives to capture the system's dynamic behavior. The simulations were then used as inputs to model the much shorter time series of water level and specific conductance at the many remaining riverine and marsh stations. This provided one set of ANN models that link the river's main channel behavior to tidal forcing and fresh water flowing down the river, and a second set that links main channel behaviors to backwater riverine and marsh behaviors.

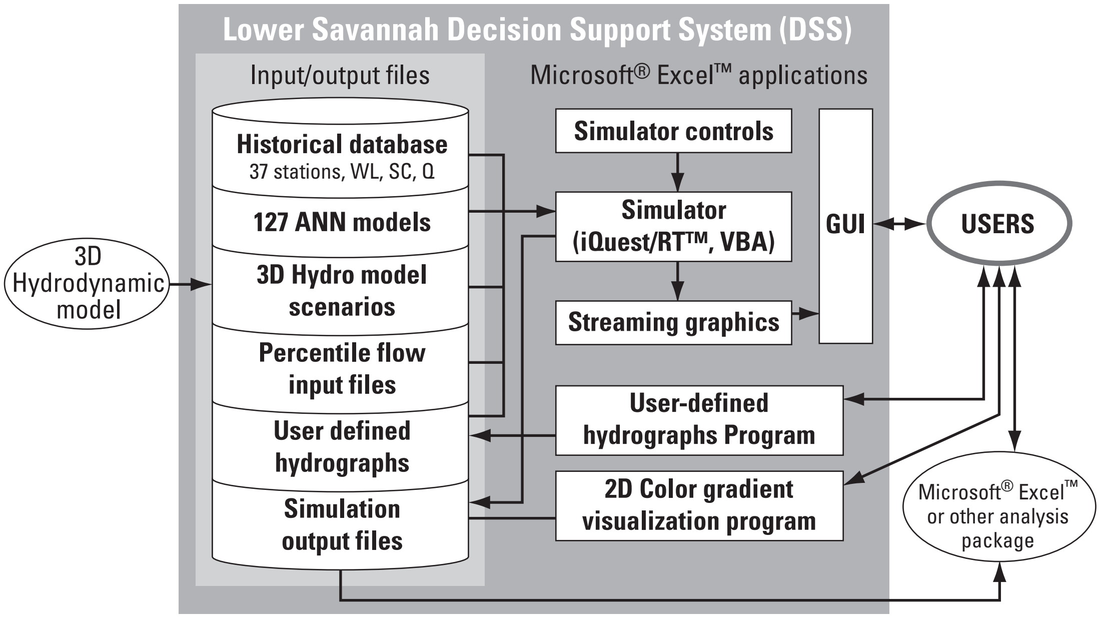


Figure 40. Architecture of the lower Savannah River Estuary Decision Support System (DSS).

Linking the 3D hydrodynamic model to the simulator is accomplished by reading in a file of simulated differences in water-level and specific-conductance values for the river, which reflect hypothetical channel geometry and replumbing scenarios run in the hydrodynamic model, to drive the riverine and marsh ANN models.

Much of the continuous data was collected during a record-setting 5-year drought, raising concerns that the relatively short time series from the riverine and marsh stations was not representative of “typical” hydrodynamic conditions. River flows had been at record lows, leading to unprecedented salinity intrusion, even without a deepened harbor (fig. 12). This concern was mitigated by the fact that the main channel ANNs were able to “learn” the full range of behaviors exhibited over 11 years, starting long before the onset of the drought. Therefore, ANNs could both “hindcast” the riverine and marsh behaviors to nondrought conditions, and be retrained on post-drought conditions as new data become available.

Model Simulation Control, User-Defined Hydrographs Program, Streaming Graphics, and Two-Dimensional Color-Gradient Visualization Program

The Simulator in the M2M DSS integrates the historical database with the 127 ANN models. The Date/Time Controls on the User Controls panel (fig. 41) are used to adjust start and end dates and time-step size for a simulation. The Simulator allows the user to run “What-if?” simulations by varying the streamflow from its historical values. The user has five Simulation Input Variable Options:

- Percent of historical Clyo streamflows,
- User-set Clyo streamflow to constant value,
- Percentile hydrograph of daily Clyo streamflow,
- User-defined daily hydrograph for Clyo streamflow, and
- 3D-model inputs at the USGS river stations and selected GPA river stations.

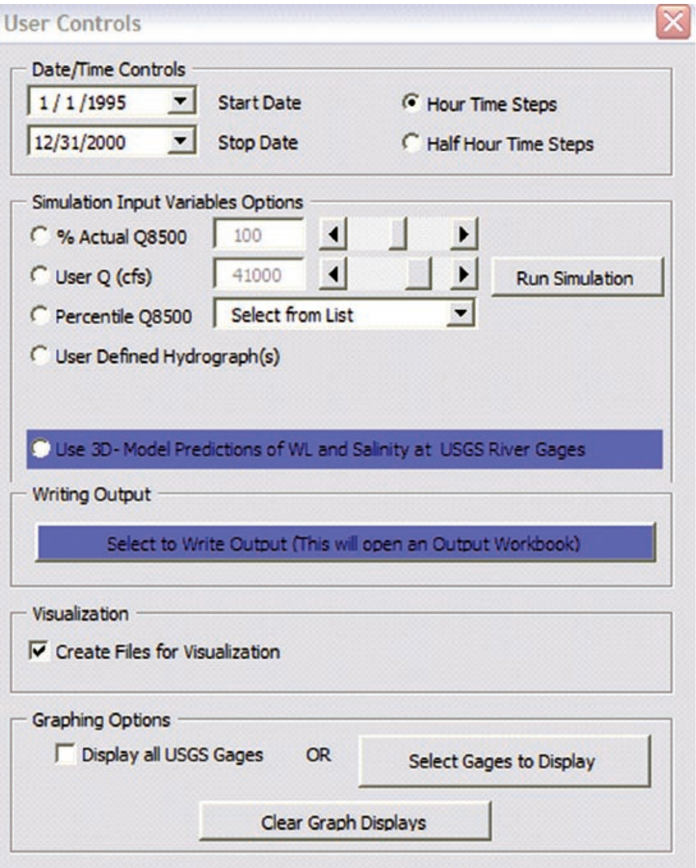
Explanations of how to use each of the options in the M2M can be found in the User’s Manual in Appendix IV.

Streaming graphics display output while a simulation is running for any four simulated variables selected by the user (fig. 42). Each graph displays the historical time series, the simulated output using the measured streamflow (to show model accuracy), and the simulated output using streamflow set by the user using the GUI controls or an input file.

To spatially visualize the marsh salinity response, the DSS is distributed with the “2D Color-Gradient Visualization Program” (fig. 43) that interpolates and extrapolates simulator output to fill and color a grid of the study area. The program provides a qualitative view of the large-scale, longitudinal gradients of the marsh parallel to the river, rather than a quantitative view of small-scale lateral gradients in the marsh perpendicular to the river. For the application, the seven USGS marsh gages were used because of the large range of measured hydrologic conditions, especially nondrought conditions, compared with the GPA marsh sites.

Although the marsh data time series provides a temporally detailed description of changing salinity conditions, the seven sites provide only information on large-scale, longitudinal gradients in the system rather than small-scale, lateral variations in the marsh. Ecological interest in marsh salinity response typically is on seasonal and annual time scales rather than the smaller time scales of riverine responses of hours and days. For the color-gradient visualization program, users can select moving window averages of 1–12 months from the M2M simulator results.

Spatial visualization is based on a 100 meter (m) (107.6 square feet) grid of the study area. The 29,000-cell grid covers the tidal marshes from I-95 to the Highway 17 bridges on the Back and Front Rivers (fig. 2). Interpolation is performed using a simple ratio of linear distances between nearest USGS marsh gages and distance from a cell to the nearest stations. To enlarge the areal extent of measured marsh data (see


User Controls

Date/Time Controls
1 / 1 /1995 Start Date
12/31/2000 Stop Date
● Hour Time Steps
○ Half Hour Time Steps

Simulation Input Variables Options
○ % Actual Q8500 100
○ User Q (cfs) 41000
○ Percentile Q8500 Select from List
○ User Defined Hydrograph(s)
○ Use 3D- Model Predictions of WL and Salinity at USGS River Gages

Writing Output

Visualization
☑ Create Files for Visualization

Graphing Options
☐ Display all USGS Gages OR

Figure 41. Simulator controls used to set parameters and run a simulation.

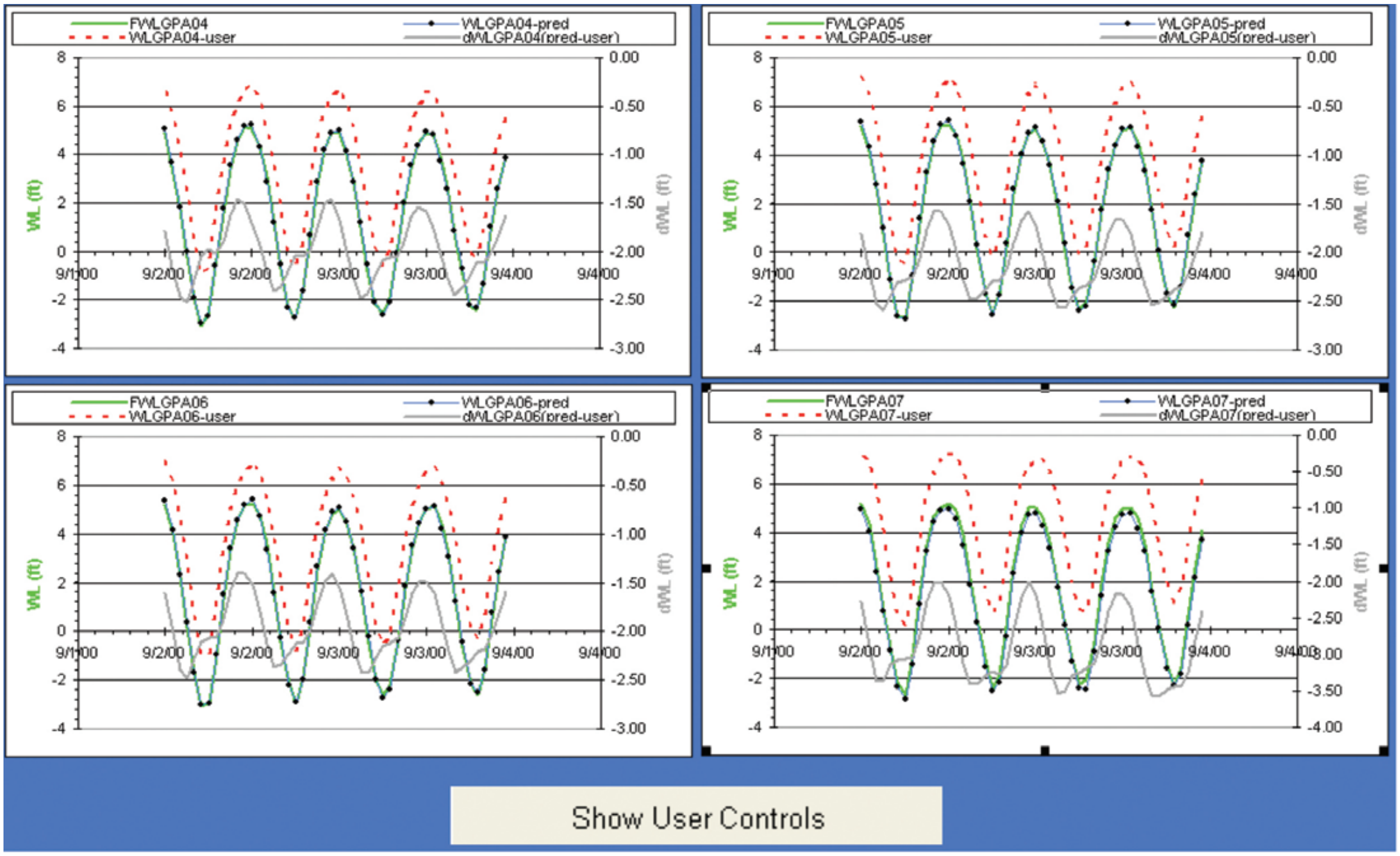


Figure 42. Streaming graphics displayed during simulation.

USGS marsh network, fig. 5*C*), riverine gages on the Savannah River at I-95 (Station 02198840, fig. 5*A*) and Back River upstream from the Tide Gate (GPA05, fig. 5*B*) were added to interpolate and extrapolate cells above Sites M1 and M2 and below Site B4.

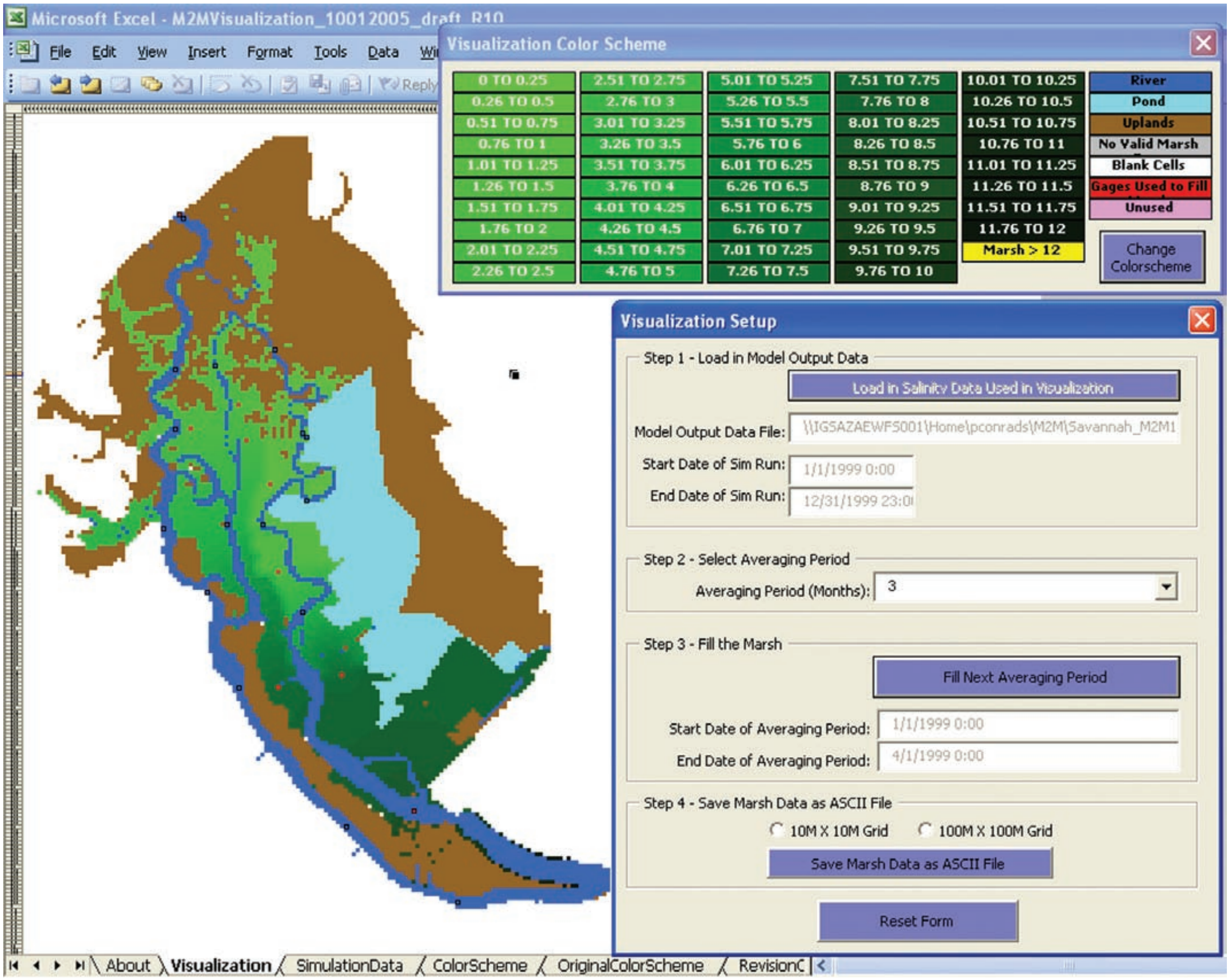
The program allows the user to configure the color scale and export all salinity values and grid parameters, i.e., cell size, and corner coordinates, as an ASCII file for input into a mapping package such as ArcView™. In addition to the 100-m grid, a 10-m (107.6 square feet) grid (2,900,000 cells) was developed to minimize numerical computation errors when overlaying the grid data and irregular polygons in GIS applications.

Application of the Model-to-Marsh Decision Support System

The development of the ANN models and the DSS application for the Savannah River Estuary had two objectives. The first was to provide the ecologists responsible for developing marsh succession models of the tidal marshes with a predictive tool that could simulate riverine water-level and salinity responses to changes in hydrologic conditions, and to simulate marsh water-level and pore-water salinity responses to changing river conditions. The models allow ecologists to evaluate the system under different hydrologic conditions to better understand the relation between riverine and marsh water-level and salinity dynamics. The second objective was to integrate predictions from the 3D EFDC model with the predictive marsh succession models. Ultimately, the M2M is a tool to assist in understanding the complex Savannah River Estuary system, and to evaluate alternative scenarios for the potential harbor deepening. The following sections describe the application of the M2M to various hydrologic scenarios.

User-Defined Hydrology

As discussed previously, salinity dynamics result from three large-scale forcing factors: (1) harbor tidal range; (2) water levels at Fort Pulaski; and (3) Savannah streamflows. Tidal range and water-level variability depend on orbital mechanics and meteorological conditions, and are not regulated. The streamflow depends on meteorological conditions, the hydrologic cycle, and a combination of regulated streamflow upstream from Augusta and unregulated streamflow downstream from Augusta. The M2M allows the user to set the input streamflow conditions to evaluate river and marsh dynamics, and alternative regulated streamflow conditions.



Visualization Color Scheme

0 TO 0.25	2.51 TO 2.75	5.01 TO 5.25	7.51 TO 7.75	10.01 TO 10.25	River
0.26 TO 0.5	2.76 TO 3	5.26 TO 5.5	7.76 TO 8	10.26 TO 10.5	Pond
0.51 TO 0.75	3.01 TO 3.25	5.51 TO 5.75	8.01 TO 8.25	10.51 TO 10.75	Uplands
0.76 TO 1	3.26 TO 3.5	5.76 TO 6	8.26 TO 8.5	10.76 TO 11	No Valid Marsh
1.01 TO 1.25	3.51 TO 3.75	6.01 TO 6.25	8.51 TO 8.75	11.01 TO 11.25	Blank Cells
1.26 TO 1.5	3.76 TO 4	6.26 TO 6.5	8.76 TO 9	11.26 TO 11.5	Gages Used to Fill
1.51 TO 1.75	4.01 TO 4.25	6.51 TO 6.75	9.01 TO 9.25	11.51 TO 11.75	Unused
1.76 TO 2	4.26 TO 4.5	6.76 TO 7	9.26 TO 9.5	11.76 TO 12	
2.01 TO 2.25	4.51 TO 4.75	7.01 TO 7.25	9.51 TO 9.75	Marsh > 12	Change Colorscheme
2.26 TO 2.5	4.76 TO 5	7.26 TO 7.5	9.76 TO 10		

Visualization Setup

Step 1 - Load in Model Output Data

Load in Salinity Data Used in Visualization

Model Output Data File: \\IGSAZAEWFS001\Home\pconrads\M2M\Savannah_M2M1

Start Date of Sim Run: 1/1/1999 0:00

End Date of Sim Run: 12/31/1999 23:0

Step 2 - Select Averaging Period

Averaging Period (Months): 3

Step 3 - Fill the Marsh

Fill Next Averaging Period

Start Date of Averaging Period: 1/1/1999 0:00

End Date of Averaging Period: 4/1/1999 0:00

Step 4 - Save Marsh Data as ASCII File

○ 10M X 10M Grid ○ 100M X 100M Grid

Save Marsh Data as ASCII File

Reset Form

Figure 43. Screen capture of the Two-Dimensional Color-Gradient Visualization Program. Left image shows spatial distribution of marsh salinity based on data from the seven USGS marsh stations. Panel in the upper right of the screen shows the user-specified color scheme. Panel in the lower right shows the user's controls of the visualization program.

Percentile and Constant Streamflow

It is instructive to analyze riverine and estuarine systems under extreme conditions. Often the critical dynamics of a system manifest themselves during these periods rather than during average hydrologic conditions. The 5-year drought (1998–2002) in South Carolina and Georgia provides an opportunity to analyze salinity dynamics and hydrologic conditions during the worst extended drought on record. To evaluate the state of the hydrology of the Savannah River for a particular year, an actual daily streamflow hydrograph can be compared to a percentile flow hydrograph. During the last year of the drought, 2002, the daily streamflow recorded at Clyo, Ga., was at or below the 5th percentile flow for the entire historical record. Figure 44 shows the actual daily 2002 streamflow at Clyo, Ga., with selected percentile flow hydrographs. During the first 5 months of the year, the streamflow was establishing new record lows. During the summer, flows generally were between the 5th percentile and the historical minimum flows. It was not until early fall that streamflows increased consistently above the 5th percentile. During the summer, large salinity intrusions were recorded throughout the USGS river and marsh gaging networks.

To evaluate the effect of low-flow conditions on the salinity response in the system, the M2M was set up to simulate a constant streamflow of 6,000 ft^3/s during 2002. The salinity response to the constant flows on the Little Back River at the USFW Dock (station 021989791) is shown in figure 45 along with the measured and constant streamflows, and harbor tidal range. Constant flow does not manifest the high streamflow

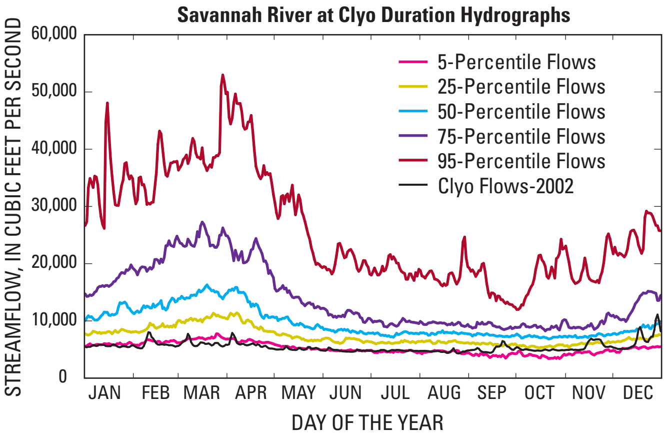


Figure 44. Duration hydrographs for Savannah River near Clyo, Ga., and daily hydrograph for the calendar year 2002 streamflows. Percentile flows are based on streamflow data from 1929 to 2003.

pulses, which exceeded 8,000 ft^3/s, in February through April and December. During the summer low-flow period, the constant 6,000 ft^3/s flow was substantially greater than the measured 2002 conditions.

The constant streamflow did not significantly affect the salinity intrusions during the first 4 months (January to April) of 2002 when the average measured streamflow was approximately 6,000 ft^3/s. During this period, the greatest intrusions occur on 14- and 28-day cycles that are co-incident with the spring tides. The three higher-flow pulses during this period did not occur during the spring tides. During the low-flow period after May, the constant flow is above the actual flow and did substantially affect salinity levels. For the actual flow conditions, the salinity intrusions (blue line) were approximately 3.0 psu, with the greatest intrusion of 8.0 psu occurring in early August. The salinity response to the constant 6,000 ft^3/s (red line) shows that the difference in the flows decreases the early salinity intrusions to approximately 1.5 to 2.0 psu, and the high intrusion in August fell to approximately 4.0 psu.

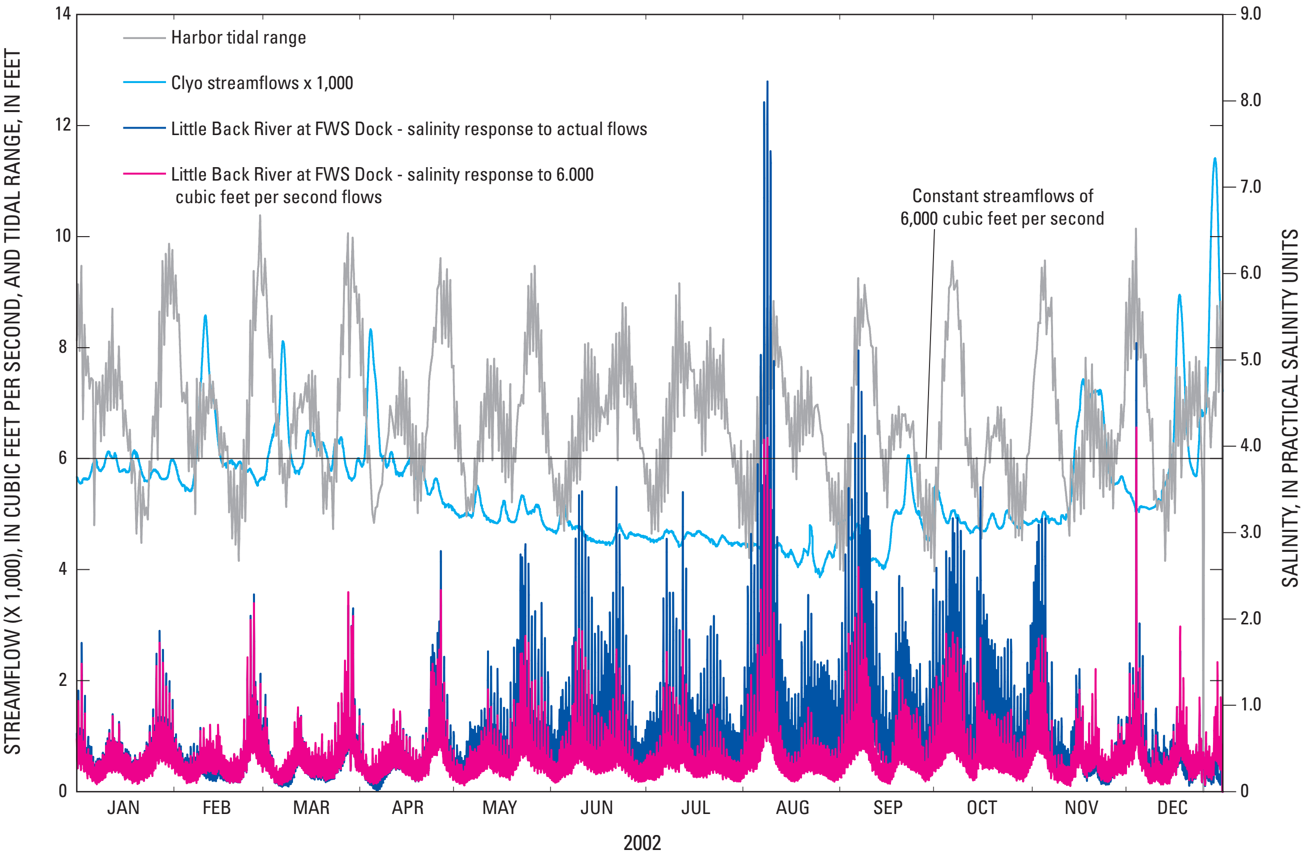


Figure 45. Salinity response at Little Back River at U.S. Fish and Wildlife Service Dock (station 021989791) for calendar year 2002 streamflows and constant 6,000 ft^3/s streamflows. Tidal range for Savannah River at Fort Pulaski (station 02198980) also are shown.

The reduction in the salinity intrusion by constant streamflow also had a substantial effect on the pore-water salinity in the tidal marshes. Figure 46 shows the pore-water salinity response to the actual and constant 6,000 ft³/s streamflows. Some of the input data for the marsh ANN models were missing during the first 3 months of the year, and predictions are not shown. For Site B1, the salinity response to the measured streamflow is between 0.5 and 1.0 psu, with the large intrusion in August being approximately 1.2 psu. The constant streamflow decreased the pore-water salinity by approximately 50 percent to 0.5 psu or less. The response to the increased streamflow virtually changed Site B1 from an oligohaline marsh to a tidal freshwater marsh (fig. 15). Downstream at Site B2, there is a similar substantial decrease in the salinity for the measured and constant 6,000 ft³/s streamflows. Note the similarities in the responses in the marsh pore-water salinity at Site B1 for measured flow conditions and Site B2 for the constant flow conditions. The slight increase in the streamflow of the constant input changed the marsh response at Site B2 to one that is equivalent to the marsh upstream during measured conditions.

Percent of Historical Streamflow

Another user-specified streamflow option is percent of historical streamflow. This allows the DSS user to modify the measured streamflow from 50 to 200 percent of the historical value. The salinity response on the Little Back River at USFW Dock (station 021989781) for a 25-percent increase in streamflow during 2002 is shown in figure 47. There is an overall decrease in salinity with high streamflow. In the constant flow simulation above, during the first 4 months the three flow pulses were decreased substantially but there was little response in salinity owing to the timing of the 28-day spring tide cycle (fig. 45). With the 25-percent increase in streamflow (fig. 47), there is a consistent reduction in the salinity, with the largest percentage reduction occurring during spring tides. During the low flows in August, the 25-percent increase in streamflows was not as great a difference over the actual streamflow as the constant 6,000 ft³/s simulation; therefore the large salinity intrusion values were reduced to 5 psu, rather than the 4 psu with the 6,000 ft³/s constant flow.

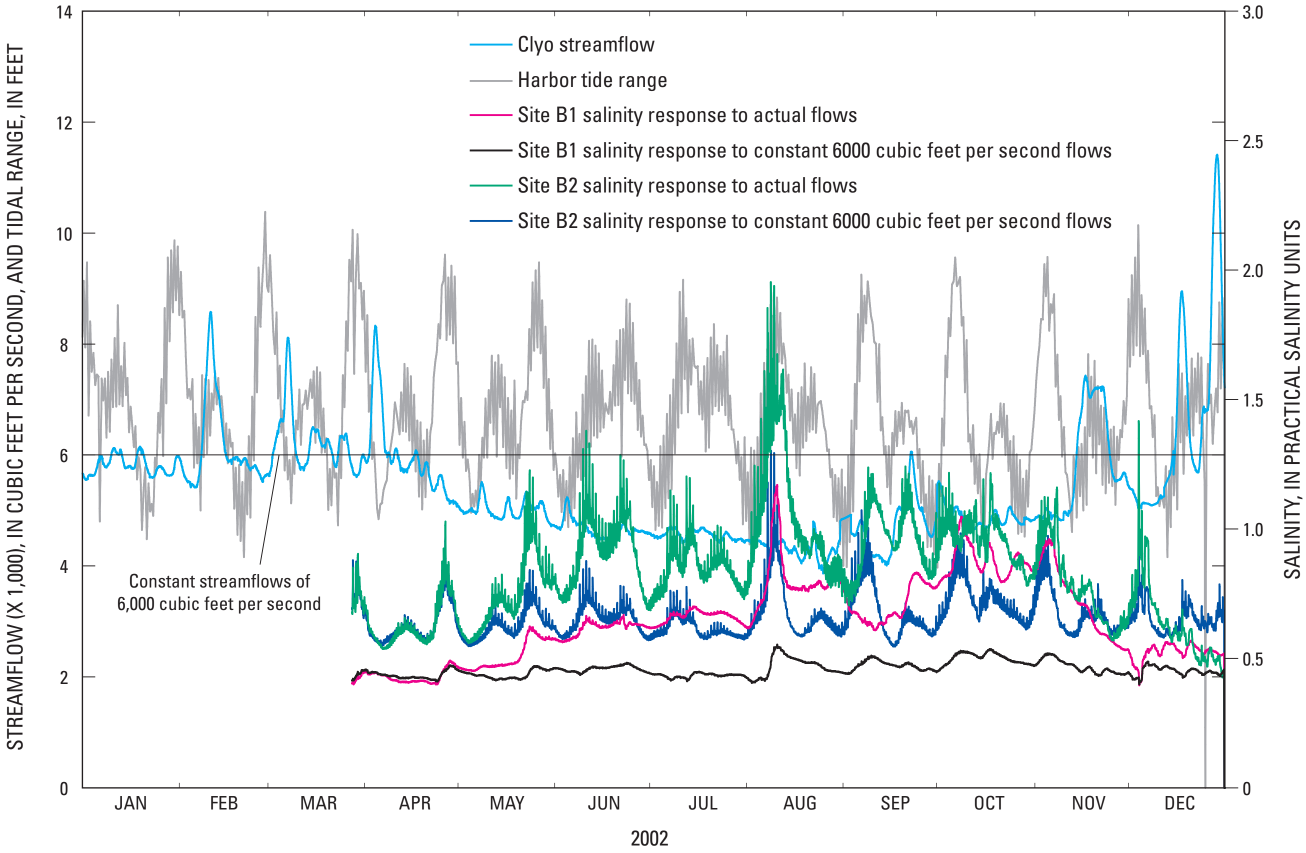


Figure 46. Hourly salinity response for two tidal marsh sites (B1 and B2) off the Little Back River for calendar year 2002 streamflows and constant 6,000 ft³/s streamflows. Tidal range for Savannah River at Fort Pulaski (station 02198980) also are shown.

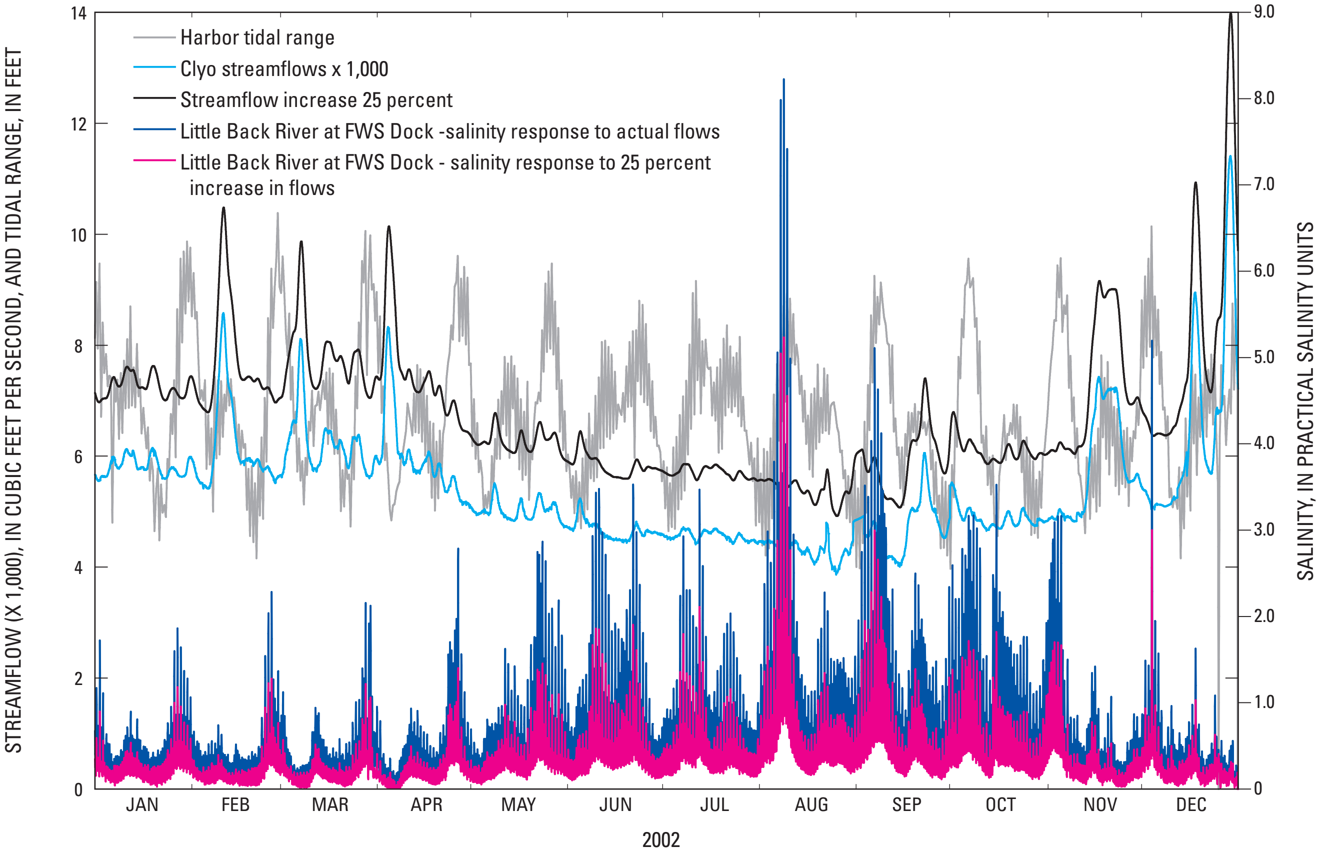


Figure 47. Hourly salinity response at Little Back River at U.S. Fish and Wildlife Service Dock (station 021989791) for calendar year 2002 streamflows and a 25-percent increase in streamflows. Tidal range for Savannah River at Fort Pulaski (station 02198980) also are shown.

The marsh response to the 25-percent higher streamflow during 2002 is shown in figure 48 for marsh sites B1, B2, and B3. The three sites have similar and different responses to higher streamflow. Generally, the three sites respond more to the higher streamflow beginning in June, with Site B3 showing the greatest response. For the 14-day period around the large salinity intrusion in August 2002, Site B2 had the greatest percentage change (approximately 300 percent) of the three sites. For 2002, Site B3 showed the largest overall response (to 0.8 psu). The different responses at the marsh sites show that percentage change in flow does not yield a consistent, proportional change in salinity.

The marsh responses to a 25-percent increase in streamflow can also be displayed as frequency distributions to reveal the changes in the occurrence of salinity in the pore-water. The cumulative percent distribution of salinity occurrences for the three marsh sites at a 25-percent increase in streamflow is shown in figure 49. For all three sites, the increase in streamflow shifts the frequency distribution to the left as pore-water salinity concentrations decrease. The differences in the slopes and the shapes of the frequency response curves show that the marshes are responding differently to marsh and river salinity dynamics. The 25-percent increase shifted the salinity frequency at Site B2 to conditions that are similar to the actual flow conditions at Site B1 upstream.

Percentile Hydrograph of Daily Streamflow

Percentile hydrographs can be used as inputs to the M2M to estimate riverine and marsh water-level and salinity responses for these graduated streamflow conditions. The user selects the time period to simulate and the percentile hydrograph to use as input. The M2M DSS will simulate the water-level and salinity responses using the measured harbor water level and tidal range data from the selected time period. The percentile flow hydrograph option allows, “normalized” water-level and salinity conditions to be determined. For example, for a period when the system is experiencing extreme low-flow conditions, a percentile flow hydrograph (for example the 25th to 75th percentile) will allow “normal” salinities and water levels to be estimated. Figure 50 shows the salinity response at the USFW Dock on the Little Back River (station 021989791) during 2002. The response for the 25th percentile flow hydrograph can be considered the “normal” response to

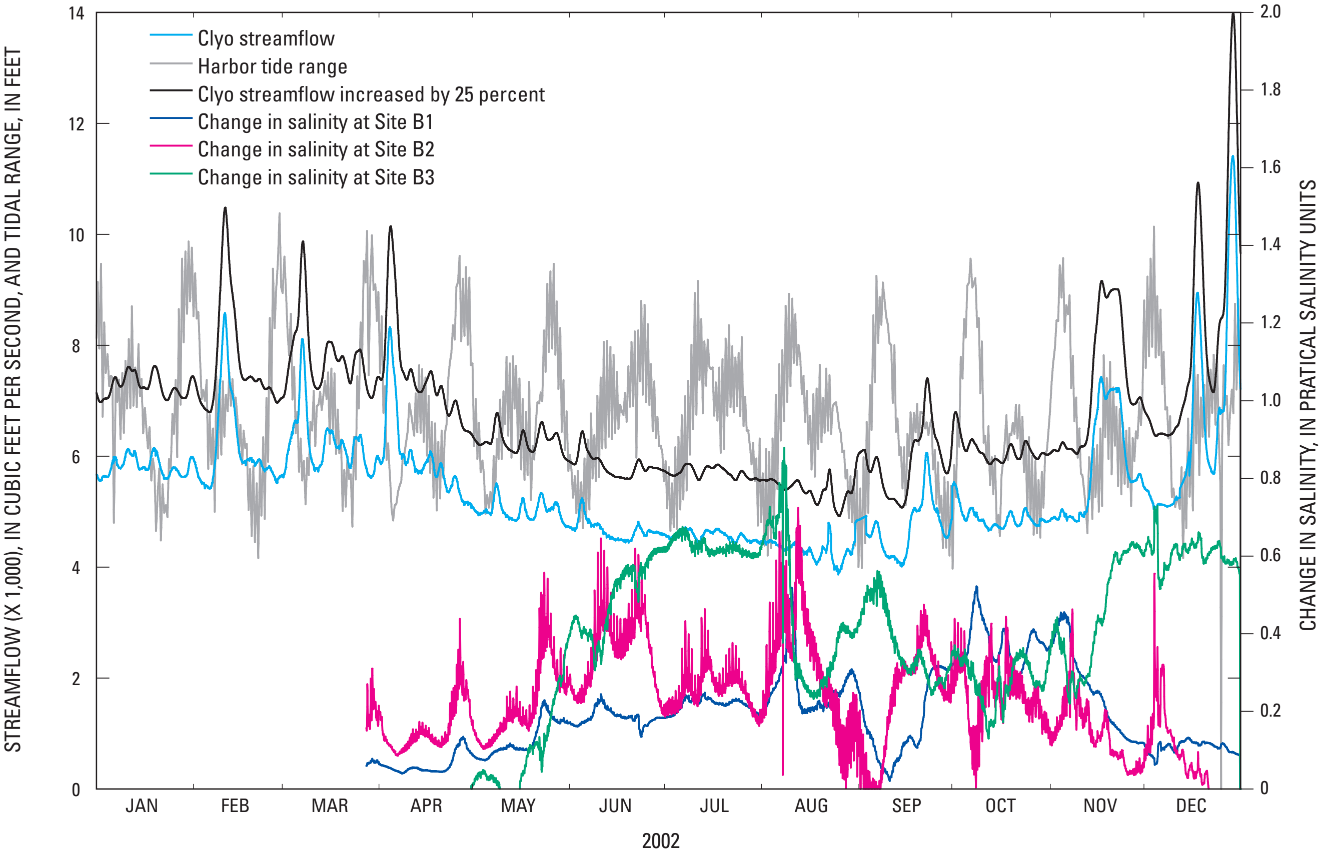


Figure 48. Hourly salinity response for three tidal marsh sites (B1, B2, and B3) along the Little Back River for a 25-percent increase in calendar year 2002 streamflows. Salinity response is the difference between salinity response for actual streamflows and a 25-percent increase in streamflows. Tidal range for Savannah River at Fort Pulaski (station 02198980) also are shown.

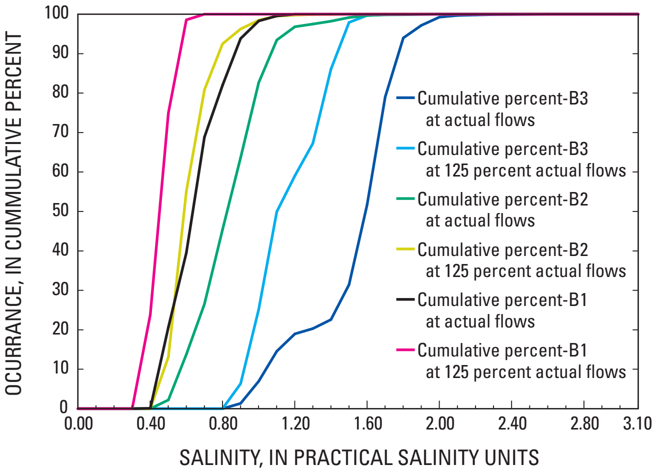


Figure 49. Frequency-distribution curves of salinity occurrence for three tidal marsh sites (B1, B2, and B3) along the Little Back River for 2002 streamflow conditions and a 25-percent increase in streamflow conditions.

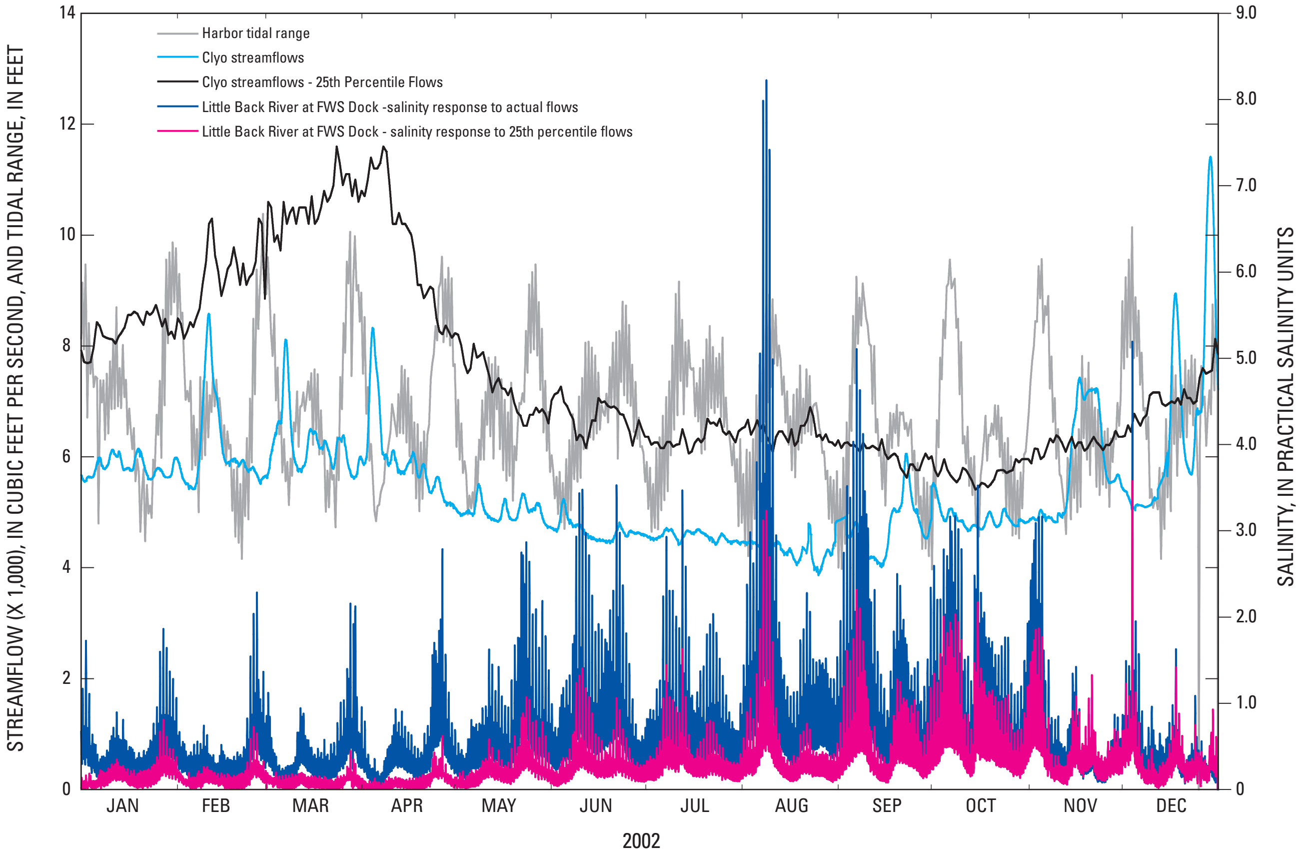


Figure 50. Hourly salinity response at U.S. Fish and Wildlife Service Dock (station 021989791) for calendar year 2002 streamflows and the 25th percentile duration hydrograph. Percentile flows based on streamflows from 1929 to 2003. Tidal range for Savannah River at Fort Pulaski (station 02198980) also are shown.

statistically derived streamflow conditions. The effect of the drought in 2002 is the difference between the salinity response to the actual flows and the 25th percentile hydrograph. During the seasonally high flows in the spring, the salinity intrusion in April is reduced from about 2.0 psu to less than 0.5 psu. During the extreme low flows during the summer, salinity intrusions of 3.0 psu are reduced to 1.0 to 1.5 psu, and 8.0 psu is reduced to 3.0 psu. With the return of slightly higher flows in the fall and winter, the reductions of the intrusions are lower.

The pore-water salinity response at three marsh sites for three different percentile flow conditions were simulated for the 2002 calendar year (fig. 51). When the streamflow is reduced to the 15th percentile, the pore-water salinities increase and the frequency distributions are shifted to the right. The frequency distribution for 15th percentile at Site B1 is similar to the 25th frequency distribution for Site B2. Further reduction in the streamflows to the 5th percentile shifts the frequency distributions even farther to the right. Sites B1 and B2 are shifted from freshwater tidal marsh to oligohaline marsh conditions.

User-Defined Streamflow Hydrograph

The fourth option for user-defined streamflow input M2M is a user-defined hydrograph. With this option, a half-hourly flow hydrograph is created outside of the M2M DSS. A simulation period is selected and the M2M uses the user-defined hydrograph and tidal conditions for the simulation period as inputs. Two scenarios were simulated using this option. In the first scenario, a hydrograph for the 2002 calendar year was created with the minimum flow set to 5,000 ft^3/s. The actual and user-defined hydrographs for 2002 and the salinity response at USFW Dock on the Little Back River (station 021989791) are shown in figure 52. During 2002, flows did not drop below 5,000 ft^3/s until May. From May to September, the minimum 5,000 ft^3/s streamflow usually is greater than the actual flow. The minimum streamflows decreased the salinity level but not as much as the constant 6,000 ft^3/s shown in figure 45. The large salinity intrusion in August was decreased by less than 1.5 psu. The apparent difference in actual and user-defined streamflow salinity responses in early

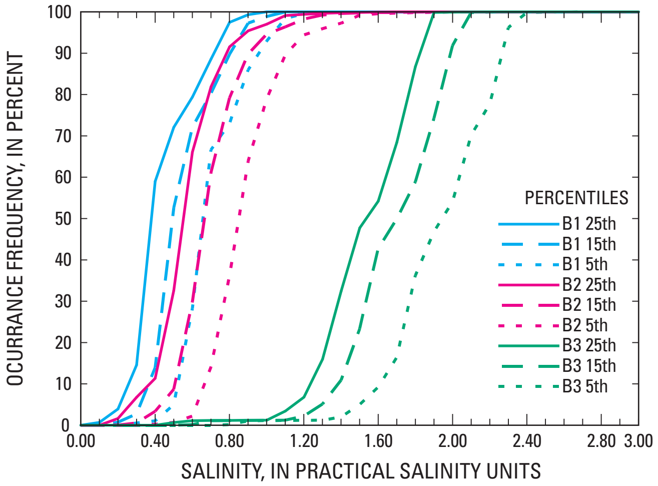


Figure 51. Frequency-distribution curves of salinity occurrence for three tidal marsh sites (B1, B2, and B3) along the Little Back River for 5th, 15th, and 25th percentile duration hydrographs.

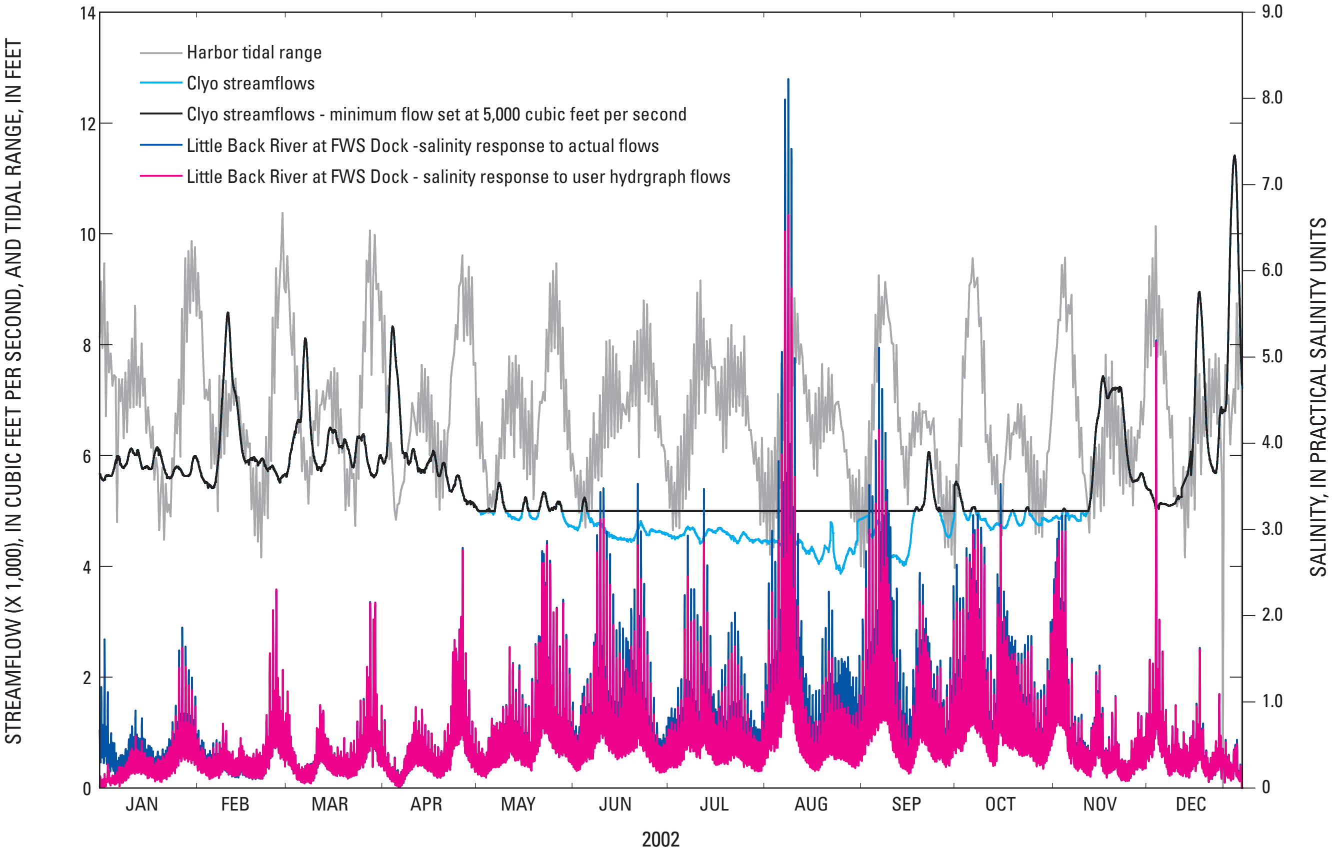


Figure 52. Hourly salinity response at U.S. Fish and Wildlife Service Dock (station 021989791) for calendar year 2002 streamflows and minimum flows set at 5,000 ft^3/s. Tidal range for Savannah River at Fort Pulaski (station 02198980) also are shown.

January are an artifact of missing 2001 values in the user-defined hydrograph for computing model inputs such as long-term time derivatives and moving window averages.

In the second user-defined hydrograph scenario (fig. 53), a hydrograph was created that shifted the higher streamflow pulses that occurred during the first 4 months of 2002 to coincide with the spring tides to evaluate whether the salinity intrusion would be substantially reduced. In addition to shifting the three pulses early in the year, a pulse of approximately 8,500 ft^3/s was inserted to coincide with the August spring tide and the coincident large salinity intrusion. The results of the simulation are shown in figure 54. The shifting of the pulses did decrease the salinity intrusions at the end of January, February, and March. The intrusion in January had the largest reduction and may be due to the larger magnitude and duration of this streamflow pulse compared to the subsequent two pulses. The timed flow pulse inserted to reduce the August salinity intrusion reduced the magnitude of the salinity intrusion by more than 4 psu.

Inputs to Model-to-Marsh from Three-Dimensional Model Output

The fifth option for user-defined inputs to the M2M DSS is output from the 3D hydrodynamic EFDC model of the Savannah River Estuary. Using this option, the differences between a historical baseline simulation and alternative harbor geometry are used for input to the M2M simulator. Inputs for the USGS marsh models include the differences from the EFDC simulations generated at the USGS river stations and at the decorrelated GPA river stations (GPA11, GPA11R, and GPA12).

One scenario was run using the historical streamflow and tidal conditions of the 1999 calendar year and a hypothetical deepening of the harbor. Two simulations were generated with the EFDC model. The first was the actual historical conditions from 1999. The second simulation was using the same boundary input conditions but a different channel geometry file representing a 4-ft deepening of the harbor. The difference between the two EFDC simulations are post-processed for the specified USGS and GPA river stations for input to the M2M simulator.

The two-dimensional color-gradient visualization program was used to display the results from the scenario. Four visualization files are generated by the M2M simulator as input to the marsh visualization program: actual conditions, simulated actual conditions, user-defined conditions, and the difference between simulated actual conditions and user-defined conditions. The user-defined conditions represent the simulated salinity values resulting from the EFDC deepening scenario. The difference between the simulated actual conditions and user-defined conditions show the effects of the scenario. Figure 55 shows the baseline simulation on the left and the user-defined condition on the right. The darker shades of green on the right panel (fig. 55*B*) indicate the increased marsh salinity concentrations resulting from a deepening of the harbor for a 2-month period in 1999.

The same deepening scenario is displayed in figure 56 as the difference between the historical condition and the deepened condition. The marsh salinity concentrations show the effect of a deepening. Figures 55 and 56 do not use the same color gradient. As expected, the effect is more evident closer to the harbor and diminishes farther upstream.

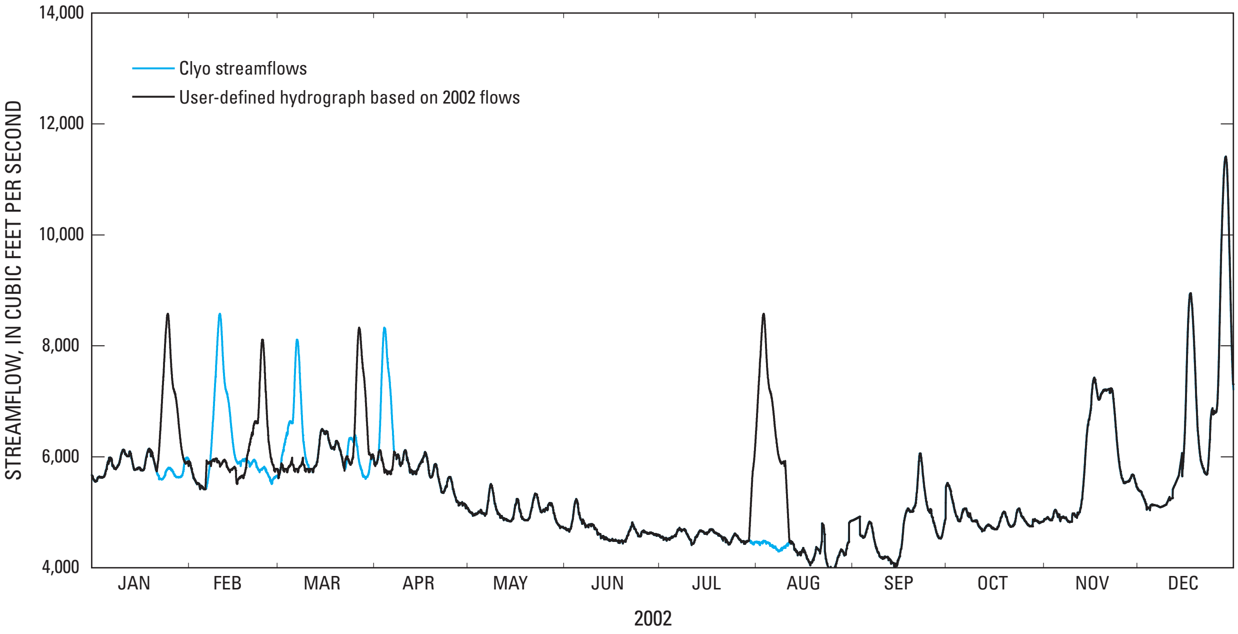


Figure 53. The 2002 streamflow hydrograph and a user-defined hydrograph for input into the Model-to-Marsh application. Hydrograph generated to time streamflow pulses to occur during spring tides and reduce salinity intrusion.

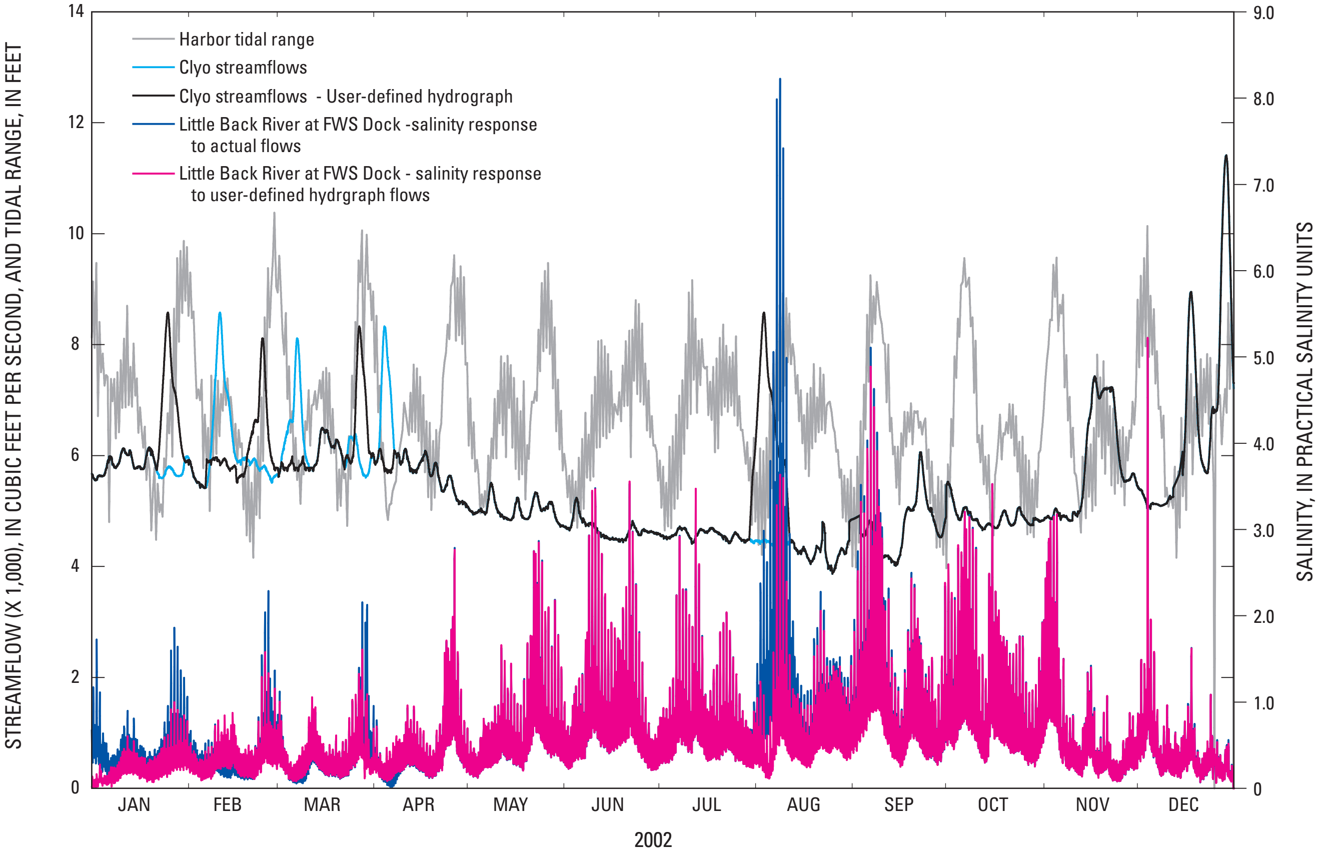


Figure 54. Hourly salinity response at U.S. Fish and Wildlife Service Dock (station 021989791) for calendar year 2002 streamflows and user-defined hydrograph with streamflow pulses inserted to occur during spring tides to reduce salinity intrusion. Tidal range for Savannah River at Fort Pulaski (station 02198980) also are shown.

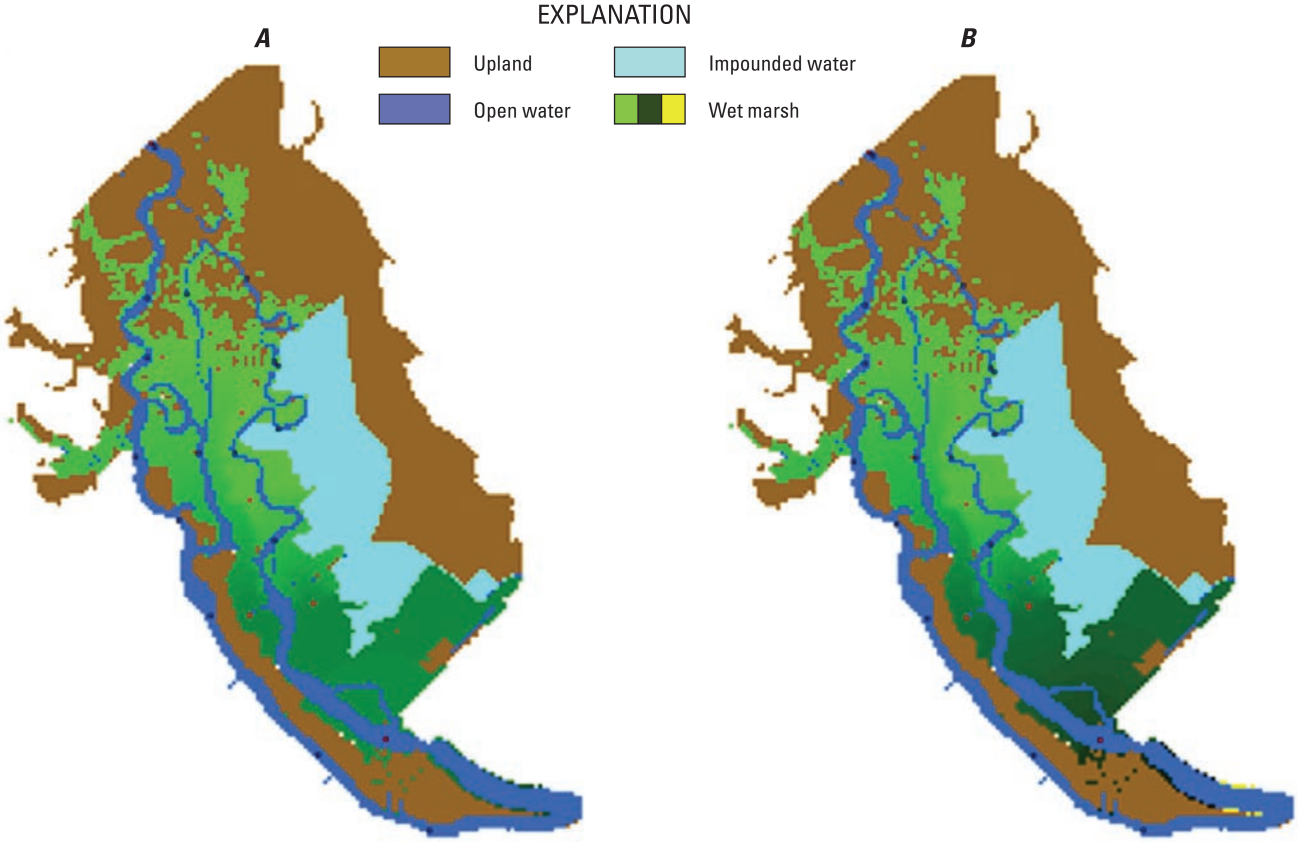


Figure 55. Two-dimensional color-gradient visualization of marsh salinity predictions for actual conditions (*A*, left panel) and a deepened condition (*B*, right panel) for the period July 1 to August 31, 1999. Both panels use the same green color gradient (values from 0.0–12 psu) to represent average marsh pore-water salinity concentrations. The panel on the right shows slightly higher (darker green) marsh pore-water salinity concentrations due to the deepening of the harbor.

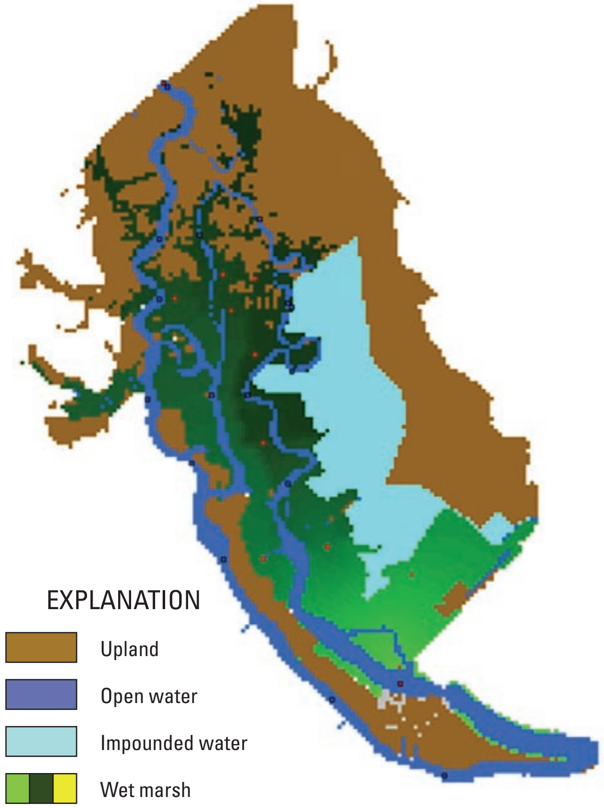


Figure 56. Two-dimensional color-gradient visualization of differences in average marsh salinity prediction for actual conditions and a deepened condition for the period July 1 to August 31, 1999. The panel uses a green color gradient (values from –3.0 to 0 psu). Lighter green color shades indicate greater differences between the two simulations.

Summary

To evaluate potential effects of a proposed deepening of the Savannah Harbor, the Georgia Ports Authority (GPA) has undertaken hydrodynamic and ecological studies of the river and marshes in the vicinity of the SNWR. The freshwater tidal marshes support a diversity of plants and wildlife and were formerly one of the largest freshwater tidal marshes along the East Coast. The potential deepening of the harbor will alter the salinity dynamics of the system and could adversely affect the freshwater tidal marshes. Two models have been developed to evaluate effects and simulate possible mitigation scenarios to minimize potential deepening effects. The GPA and the U.S. Army Corps of Engineers funded the development of hydrodynamic and ecological models to evaluate the potential effects of a proposed deepening of Savannah Harbor. A three-dimensional (3D) hydrodynamic and water-quality model was developed that simulates water levels and salinity throughout the riverine network for anticipated changes in shipping channel geometry. The other models are marsh succession models that predict the changes in marsh plant communities as a result of changes in marsh pore-water salinity. To link the predictive capacity of the two modeling efforts, artificial neural network (ANN) models were developed using data-mining techniques to simulate riverine and marsh water-level and salinity dynamics.

The river and marsh ANN models, historical database, model simulation controls, streaming graphics, and model output were integrated into a decision support system (DSS) named the Model-to-Marsh (M2M). The M2M can be run under two different modes. One mode allows the user to manipulate the streamflow inputs to the system. Four options are available: constant streamflows, percent of historical streamflows, percentile streamflow hydrographs, and user-defined hydrograph. The other mode allows users to input the simulated change in riverine conditions from the 3D hydrodynamic model. Output from the M2M includes tabular time series of measured data, predictions of the measured data, predictions of the user-specified conditions, and differences in simulated and user-specified values. A two-dimensional (2D) plan view visualization routine was also developed that displays marsh salinity conditions. The visualization routine uses marsh predictions at seven locations and interpolates and extrapolates values across the marsh on either a 10- or 100-meter grid. The 2D grid is formatted to be compatible with geographic information system (GIS) applications. The M2M is a spreadsheet application that facilitates the dissemination and utility of the DSS.

The empirical ANN models were developed using data-mining techniques. Data mining is a powerful tool for converting large databases into knowledge to solve problems that are otherwise imponderable because of the large numbers of explanatory variables or poorly understood process physics. Since the last harbor modification in 1994, there are four databases of time series of river and marsh water level and specific conductance (field measurement for salinity). The USGS has maintained a network of continuous streamflow, water-level, and specific-conductance river gages since the 1980s and a network of continuous tidal marsh water-level and salinity gages since 1999. To support the 3D hydrodynamic model development, the GPA collected continuous water-level and water-quality data during the summers of 1997 and 1999. The GPA also collected continuous tidal marsh water-level and specific-conductance data from 1999 to 2002.

Development of models with good predictive ability through the full range of historical conditions is dependent on the availability of measured data covering the full range of conditions in the system. Depending on the period of time when these data collection networks were active, each data set covered different ranges of Savannah River streamflow conditions. For the river networks, the USGS stations recorded water level and specific conductance for the full range of historical streamflow conditions from 4,320 to 52,600 ft^3/s. The GPA network measured conditions for a flow range of 5,440 to 11,600 ft^3/s, which represents median flow conditions (the 25th and 75th percentiles for the period of record). For the tidal marsh networks, the USGS gaging network measured hydrologic conditions of 4,320 to 39,600 ft^3/s, which represents a low- to high-flow condition (from minimum flow to greater than 95th percentile flows for the period of record). The GPA network measured conditions from 4,320 to 14,100 ft^3/s, which like the GPA river network, represents median flow conditions.

For the application of the ANN models to the Savannah River, data-mining methods are applied to maximize the information content in raw data. Signal processing techniques included signal decomposition, digital filtering, time derivatives, time delays, running averages, and differences between stations. Signal inputs to the ANN model used “state space reconstruction” (SSR) for representing dynamic relations of the system. The development of ANN models to simulate the water level and pore-water salinity of the tidal marsh was undertaken in two phases. The first phase was to train ANN models to simulate the water level and specific conductance at the USGS and the GPA riverine sites. Inputs to the ANN models of the USGS river network include time series, or signals, of streamflow, tidal water level, and tidal range. The second phase was to train ANN models to simulate water level and pore-water specific conductance at the USGS and the GPA marsh sites. Inputs for these models include the water-level and specific-conductance signals from the USGS river network at the marsh gaging sites.

For a complex system like the Savannah River Estuary and tidal marshes, the statistical accuracy of the models and predictive capability are satisfactory. The salinity models are able to simulate the 14- and 28-day salinity intrusion cycles in the rivers and capture the salinity dynamics responses in the marshes. The models of the USGS river and marsh networks have the greatest range of the output variables. Generally, the river water-level models have coefficient of determination (R^2) values ranging from 0.88 to 0.99 and the specific-conductance models have R^2 values ranging from 0.57 to 0.87. The marsh water-level models have R^2 values ranging from 0.72 to 0.87 and the specific-conductance models have R^2 values ranging from 0.53 to 0.85.

The M2M application was used to simulate four user-specified flow options in the applications. The first scenario simulated the 2002 conditions using a constant streamflow of 6,000 ft^3/s. During the low-flow conditions in the summer when the actual flows were less than 6,000 ft^3/s, there was a reduction in the salinity intrusion into the Little Back River. The constant 6,000 ft^3/s reduced the amount of streamflow for three higher streamflow pulses that occurred in the spring of 2002. The reductions in the streamflow did not cause an increase in the salinity intrusion for these three events related to the timing with the 28-day spring tidal cycle. For the Little Back River, salinity intrusion is greatest during spring tides, and the three higher streamflow pulses did not occur during the optimal tidal phase. The constant streamflow also had a significant effect on the pore-water salinity response in the tidal marshes. The response to the increased streamflow during the low-flow conditions of the summer essentially changed Site B1 from an oligohaline marsh to a tidal freshwater marsh.

A second option for user-specified inflows for the M2M application is percent of historical streamflows. A 25-percent increase in streamflow for 2002 was simulated, and there was an overall decrease in the salinity with the increase in flow. With the 25-percent increase in streamflows, salinity intrusion is reduced during these periods due to the increase in streamflow with the largest percentage reductions occurring during spring tides.

Percentile hydrographs can be used as a third option as inputs to the M2M to estimate riverine and marsh water-level and salinity response for these streamflow conditions. Using the percentile flow hydrograph option, “normalized” water-level and salinity conditions can be determined for a particular time period. Three percentile streamflow conditions, the 5th, 15th, and 25th percentile hydrographs, were simulated with the M2M application for the 2002 calendar year. The marsh response for these conditions showed Sites B1 and B2 shifting from freshwater tidal marsh conditions to oligohaline marsh conditions as flow conditions were reduced from the 25th to the 5th percentile.

The fourth option for streamflow inputs to the M2M application is a user-defined hydrograph. For this scenario, a hydrograph was created that shifted the higher streamflow pulses that occurred during the first 4 months of 2002 to coincide with the spring tides to evaluate whether the salinity intrusion would be significantly reduced. The shifting of the three pulses to coincide with the spring tides did decrease the salinity intrusions at the end of January, February, and March 2002.

The final option for inputs to the M2M application is output from the 3D EFDC model. For this scenario, the EFDC model was used to simulate the effects of a hypothetical 4-ft deepening of the harbor based on the historical hydrologic and tidal conditions for calendar year 1999. The differences at selected USGS and GPA river gages were post-processed and used as input to the M2M. The 2-month average marsh salinities for the period July through August 1999 showed the highest effects in the marshes closest to the harbor and proximal to the Front River with diminishing increases farther upstream.

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